

# **Seismic Risk in Jordan**

**by**

**Robert L. Kovach**

**9 July 1987**

**U.S. Geological Survey, Menlo Park, California, Department of Geophysics,  
Stanford University.**

**U.S. Geological Survey  
Open File Report 87-358**

**This report is preliminary and has not been  
edited or reviewed for conformity with  
Geological Survey Standards and nomenclature**

**Table of Contents**

<b>1. Introduction</b>	<b>1</b>
<b>2. Locus of Damaging Historical Events</b>	<b>1</b>
<b>3. Seismic Intensities in Jordan</b>	<b>3</b>
<b>4. Seismic Intensities and Ground Acceleration</b>	<b>6</b>
<b>5. Estimation of Seismic Risk in Jordan</b>	<b>10</b>
<b>6. Acknowledgments</b>	<b>13</b>
<b>7. References</b>	<b>14</b>

**List of Figures**

<b>Figure 2-1: Historical Seismicity of Jordan and Vicinlty (Kovach et al. 1986).</b>	<b>2</b>
<b>Figure 3-1: Isoseismals for the 1837 Safed Event and the 1927 Jericho Event Compared with the Proposed Jordan Building Code.</b>	<b>7</b>
<b>Figure 3-2: Seismic Intensity Distribution of the September 2, 1973, Earthquake (Arieh et al. 1977).</b>	<b>8</b>
<b>Figure 3-3: An Estimated Seismic Intensity Map for Jordan.</b>	<b>9</b>
<b>Figure 5-1: Recurrence Relation for the Northern Dead Sea Rift Zone.</b>	<b>11</b>
<b>Figure 5-2: Equi-Risk (Probability) Contours for Jordan and Vicinity for Seismic Intensities of ~VI in 50 years.</b>	<b>12</b>

**List of Tables**  
**Table 2-1: Events of  $\geq 6.1$  in Jordan and Vicinity**

**4**

## 1. Introduction

Seismic risk is routinely expressed as the probability that a certain value of seismic intensity, earthquake magnitude or a specific ground motion parameter such as peak ground acceleration, velocity or displacement will not be exceeded at a specific location within a specific interval of time.

It is clear that ground accelerations, for example are best determined from records obtained by strong motion instruments or accelerographs during earthquakes. However, in Jordan such records are not yet available, particularly for large earthquakes and one must rely on estimated values of ground acceleration inferred from seismic intensities or magnitudes of historical events. There are shortcomings in the approach of using macroseismic intensity as the quantity characterizing earthquake effects, and one is further constrained, in the case of Jordan, in that the number of observations is small and the return periods of severe damaging shocks are large.

The purpose of this present paper is to review some of the historical seismic intensity data pertinent to Jordan, make a preliminary estimate of maximum seismic intensities and ground accelerations which might be expected and finally to address briefly the question of the probability and return times of such events occurring.

## 2. Locus of Damaging Historical Events

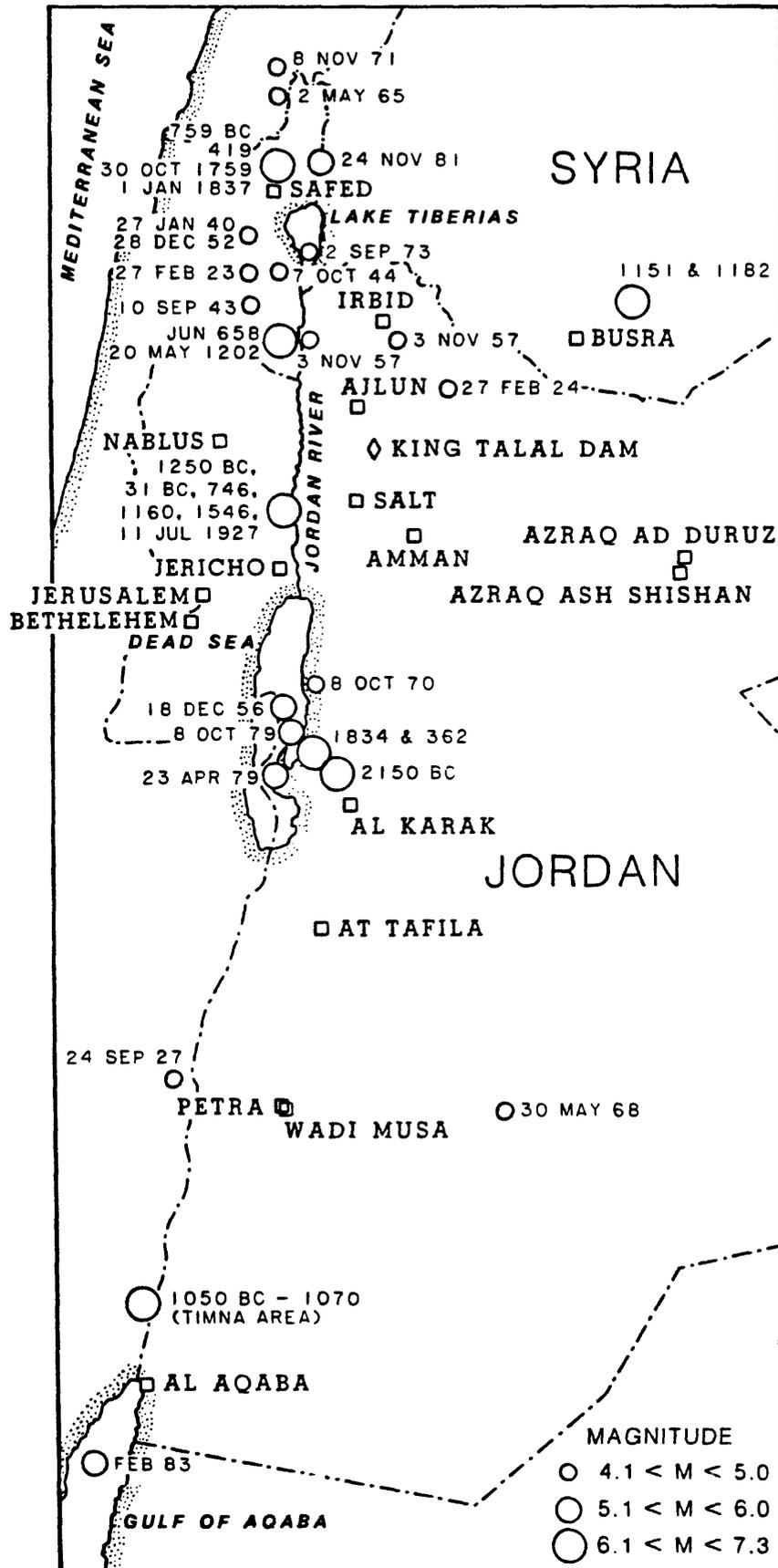
An examination of the historical seismicity map of Jordan and its vicinity reveals that there are six epicentral clusters of recorded events of reported or deduced magnitude, in excess of  $M = 6.1$  (Figure 2-1).

In the north, these magnitudes were the events of 759 B.C., and 419, 1759 and 1837 A.D. centered near Safed (Ben-Menahem, 1979). West of Irbid, along the axis of the Dead Sea Rift zone were the events occurring in 658 and 1202 which caused severe damage in Nablus. Inferred magnitudes were  $M = 6.6$  and  $6.8$  respectively, with reported Mercalli intensities of at least IX.

In the vicinity of Jericho are the well-documented events of 1250 B.C., 31 B.C., 746, 1160, 1546 and 11 July 1927 A.D. Magnitudes are estimated to range from 6.25 to 7.0.

Near Karak are the events of 2150 B.C. (possibly the destruction of Sodom and Gommorah?), 362 and 1834 A.D. The 1834 event is of particular interest in that major damage was reported in Jerusalem, Bethlehem, Nablus and Karak.

Figure 2-1: Historical Seismicity of Jordan and Vicinity (Kovach et al. 1986).



In the vicinity of Aqaba four events in the magnitude range of 6.2 to 6.5 have been described which occurred over the time interval from 1050 B.C. to 1070 A.D. (Ben-Menahem, 1979).

The exact location of the events of 1151 and 1182 placed in the Hauran district of Syria are probably debatable although the time of these events was reported by Arvantakis (1903), Milne (1911), Perrey (1850), Willis (1928) and subsequently catalogued by Ben-Menahem (1979).

The locations of other recorded and documented events are also shown in Figure 2-1. Table 2-1 lists the events of magnitudes equal to or greater than 6.1 which have occurred in the region of interest. The maximum earthquake magnitudes lie in the range from about 6.1 to 7.3. This range of magnitudes can be used in the practical assessment of seismic risk for Jordan and its vicinity. It is less probable but not impossible that larger earthquakes could occur with long recurrence times, ranging from 2,000 - 5,000 years.

### 3. Seismic Intensities in Jordan

The earthquakes described in the previous section suggest maximum Mercalli intensities of about IX as being representative of large earthquakes in this region. Certainly the best evidence comes from the well-documented isoseismal maps generated for the 1837  $M = 6.4$  Safed event and the 1927  $M = 6.25$  Jericho event (Vered and Striem, 1977). Isoseismal contours for these two events are shown in Figure 3-1 superimposed on the seismic zoning map for Jordan proposed by the Royal Scientific Society.

The shape of the isoseismal contours for the two events are elongated ellipses, but surprisingly similar in that translating the center of the contours of one event to the epicentral location of the other would, to first order, describe the seismic intensity distribution. [If complete symmetry of the earthquake source and earth structure existed about the vertical through the hypocenter of the earthquake the isoseismals would be circular centered on the epicenter.] Even though it can and should be argued that there are many unsymmetrical factors which influence the distribution of seismic intensities, such as local soil conditions, fault rupture length, type of faulting etc. one can assume without malice a general elliptical pattern for seismic intensities for events along the axis of the Dead Sea Rift. Figure 3-2 shows the seismic intensity map for the magnitude 4.5 Jordan Valley earthquake of September 2, 1973 (Arieh et al. 1977) which also demonstrates for this much smaller event a general north - south elliptical contour pattern for intensities in the range of V-VII.

Under the assumption of the similarities in the isoseismal maps of the 1837 and 1927 events Figure 3-3 shows the constructed isoseismal intensity distribution considered plausible for

Table 2-1: Events of  $\geq 6.1$  in Jordan and Vicinity

DATE	LOCATION	COMMENTS
~2150 B.C.	Bab-a-Dara'a east of Lisan	Destruction of Sodom & Gomorrah? M=7-7.3
1250 B.C.	32°N, 35.5°E	Destruction of Jericho, M=6.5
1050 B.C.	Near Timna	Destruction at Timna copper mines. M=6.2
759 B.C.	33°N, 35.5°E	Maximum intensity =11; Intensity at Jerusalem MM=8
31 B.C. Sep. 2	32°N, 35.5°E	Destruction in Qumran & Jericho M=7.0
48 A.D.	Wadi 'Araba	Destruction of Nabatean temples at Ram, 40 km east of Aqaba & at Petra, M=6.2
362, May 24	31.3°N, 35.6°E	Destruction of Karak; tsunami in Dead Sea, M=6.4
419	33°N, 35.5°E	M=6.2
658, June	32.5°N, 35.5°E	M=6.6
746, Jan. 18	32°N, 35.5°E	Maximum intensity MM=11, damage in Tiberias, Jericho in Dead Sea, M=7.
1067, April 20	Wadi 'Araba	Destruction of Eilat, M=6.5
1070, Feb. 25	Wadi 'Araba?	Damage in Cairo, felt in Jerusalem, M=6.5
1151	32.6°N, 36.7°E	Maximum intensity =9, destructive at Busra (Bostra) in southern Syria, MM max=9. M=6.2

**Table 2-1 (cont.): Events of  $\geq 6.1$  in Jordan and Vicinity.**

<b>DATE</b>	<b>LOCATION</b>	<b>COMMENTS</b>
1160	32°N, 35.5°E	Destructive, M=6.1
1182	32.6°N, 36.7°E	Maximum intensity =10, destructive in Busra and in numerous villages in Syria, M=6.7
1202, May 20	32.5°N, 35.5°E	Maximum intensity =10-11, Nablus destroyed, M=6.8
1546, Jan. 14	32°N, 35.5°E	Maximum intensity =10-11, damage in Karak, Salt, & Nablus, tsunami in Dead Sea, M=7.0
1759, Oct. 30	33°N, 35.5°E	Heavy damage in Safed, M=6.5
1834, May 23	31.3°N, 35.6°E	Maximum intensity =9, damage in Karak, Nablus, M=6.3
1837, Jan. 1	33°N, 35.5°E	Maximum intensity =9, heavy damage in Safed, well-studied event, M=6.4
1927, July 11	32°N, 35.5°E	Great damage, 500 fatalities, first large earthquake to be instrument recorded, M=6.25

Jordan based on the historical location of events having measured and inferred magnitudes in the range of 6.1 to 7.3 for similar earthquakes along the Dead Sea Rift. The Hauran events of 1151 and 1182 were not utilized in the construction of Figure 3-3.

Figure 3-3 can be considered as a reasonable representation of the seismic intensities from future seismic events along the Dead Sea Rift which might effect Jordan. It should be emphasized that this map only represents the expected intensities based on past events and does not address the problem of the time frame or probability of when such an event would occur.

#### 4. Seismic Intensities and Ground Acceleration

Correlations are often made between horizontal peak ground acceleration  $A(\text{cm/s}^2)$  with the maximum Mercalli intensity  $I_{MM}$  observed for an earthquake. Seismic intensity, by definition is directly linked to damage (Evernden and Thomson, 1986) yet peak ground acceleration is desired by engineers for the development of building codes. Any correlations, therefore, should be taken as guidelines, a necessary constraint when utilizing historical earthquake data in the absence of instrumental measurements.

Trifunac and Brady (1975) in a correlation study of the modified Mercalli intensities observed for 57 western United States earthquakes in the range of  $IV \leq I_{MM} \leq X$  and 187 strong-motion accelerograms determined a useful regression model for horizontal peak accelerations  $A$ :

$$\log_{10} A (\text{cm/s}^2) = 0.01 + 0.30 I_{MM}$$

Such a model would suggest for  $I_{MM} = IX$  peak horizontal ground accelerations of  $\sim 0.5g$ . However, as Trifunac and Brady (1975) point out the spread of the measured peak values of strong ground motion is quite large.

In a thorough analytical-empirical study of middle eastern seismicity Ben-Menahem, Vered and Brooke (1982) derived the following empirical relation which relates the local horizontal bedrock acceleration to the modified Mercalli intensity.

$$\ln A = 0.5 + 0.60 I_{MM}$$

This relation, believed to be appropriate for events along the Dead Sea Rift Zone, would suggest, for a maximal intensity of  $IX$ , a peak horizontal ground acceleration of  $\sim 0.37g$ , slightly less than that inferred from the western U.S. data set.

It is therefore likely that peak horizontal accelerations in the range of 0.4 to 0.5g are expected

**Figure 3-1: Isoseismals for the 1837 Safed Event and the 1927 Jericho Event Compared with the Proposed Jordan Building Code.**

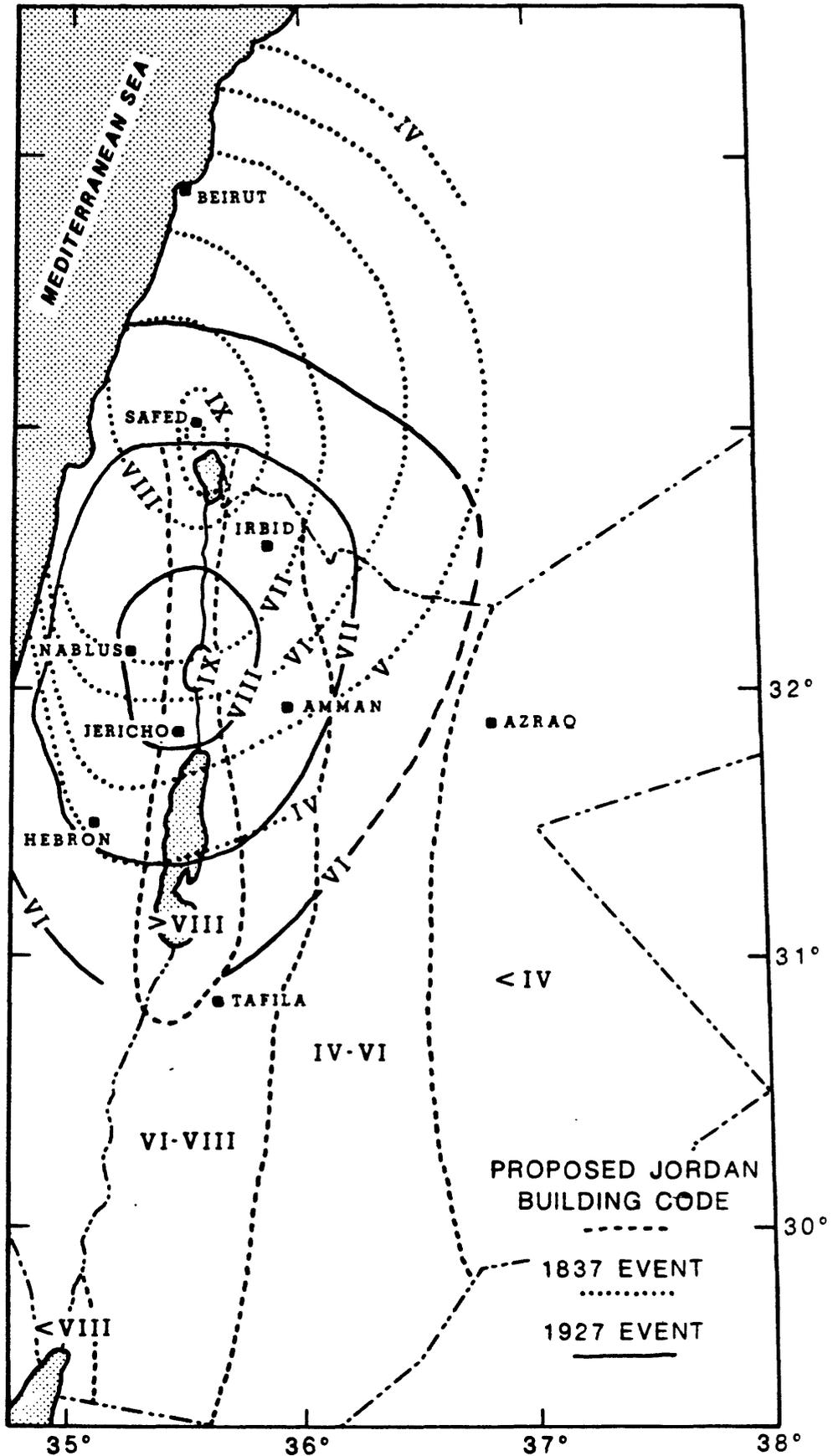


Figure 3-2: Seismic Intensity Distribution of the September 2, 1973, Earthquake (Arieh et al. 1977).

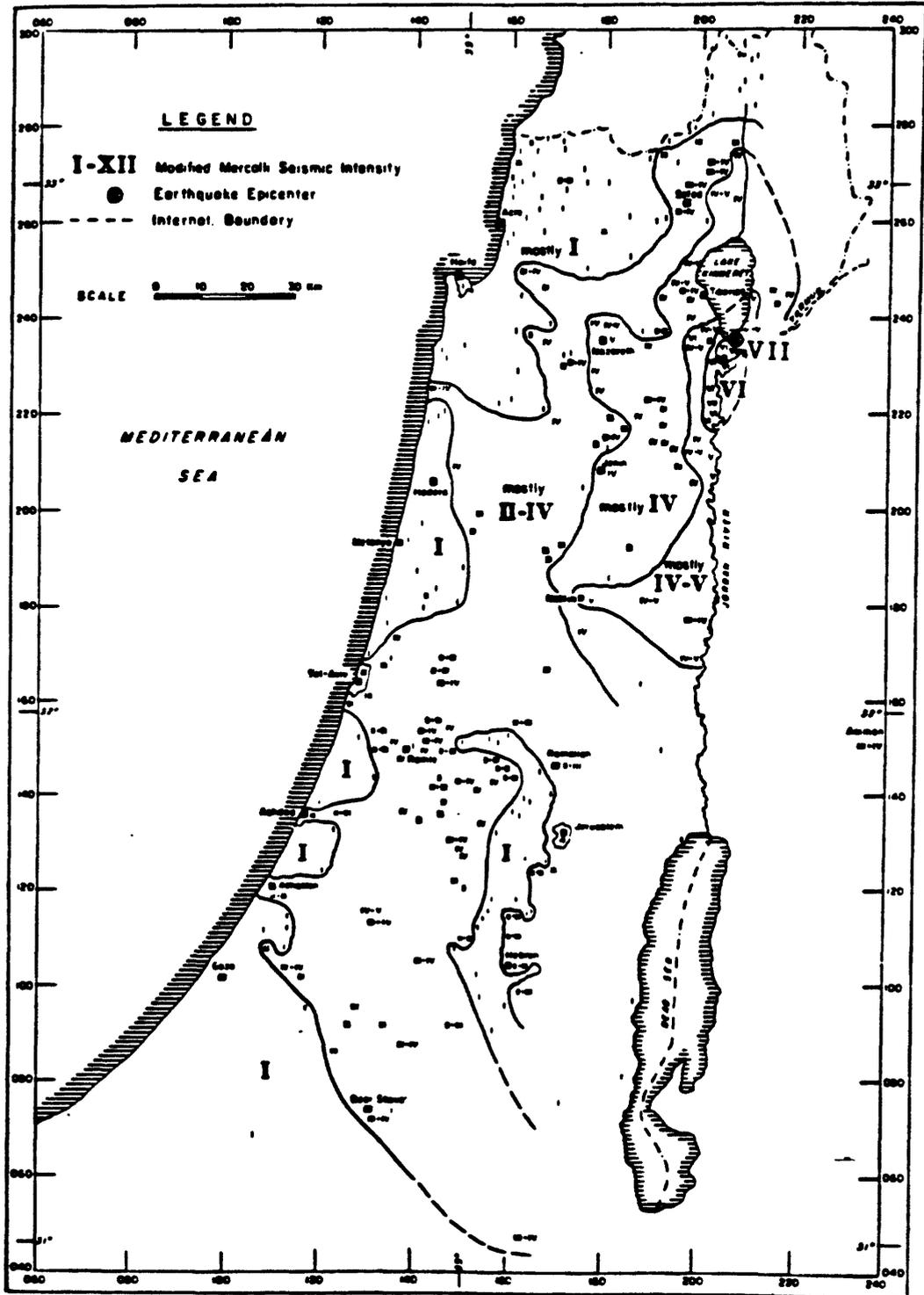
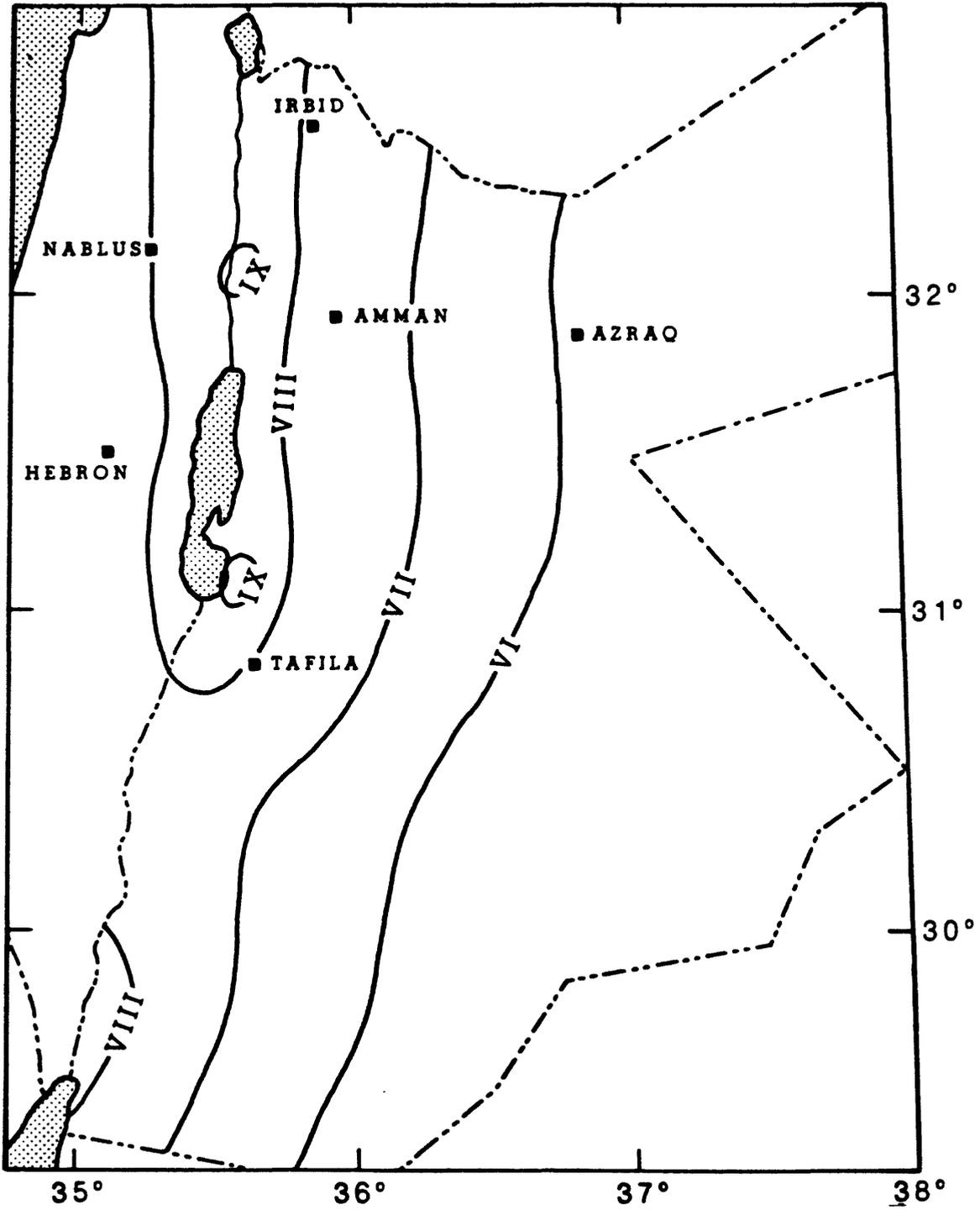


Figure 3-3: An Estimated Seismic Intensity Map for Jordan.



in Jordan, based on an assessment of the historical seismic record. However, it needs to be emphasized that this estimate is based on the maximum intensity reported. Accelerations greater than 0.5g are likely at close distances to the epicenter.

## 5. Estimation of Seismic Risk in Jordan

The primary earthquake source region in terms of historical damaging activity is that portion of the Dead Sea Rift which extends from 30.8°N to 33.3°N latitude. A plot of the earthquake recurrence data from 2150 B.C. to 1979 taken from the catalog of Ben-Menahem (1979), and the microearthquake data of Ben-Menahem, Aboodi, Vered and Kovach (1977) is shown in Figure 5-1. The data covering the Dead Sea fault system from 30.8°N to 33.3°N support the relation

$$\log_{10}N = 3.10 - 0.86M$$

where N is the number of earthquakes per year with magnitudes greater or equal to M. This relation can be used to determine a mean return period, T, of

$$T = 10^{0.86M - 3.10} \text{ years.}$$

For example a return period of 115 years is expected for a M = 6.0 event and a return period of 2 years for a M = 4.0 earthquake, in agreement with recent instrumental observations.

Under the assumption of a Poisson process the probability of the occurrence of an earthquake with a magnitude greater or equal to M within a period of  $\Delta T$  years (taken to be the earthquake risk) is given by the relation

$$P(\Delta T|M) = 1 - \exp(-\Delta T/T(M))$$

where T(M) is given by the frequency - magnitude recurrence relation

$$T(M) = 10^{bM-a}$$

where a and b are derived from

$$\log_{10}N = a - bM.$$

Thus, along the northern section of the Dead Sea Rift there is an expected probability of 0.96 that an earthquake of magnitude 5.0 will occur within 50 years and a probability of 0.35 that a magnitude 6.0 event will take place in this same time frame.

Figure 5-1: Recurrence Relation for the Northern Dead Sea Rift Zone.

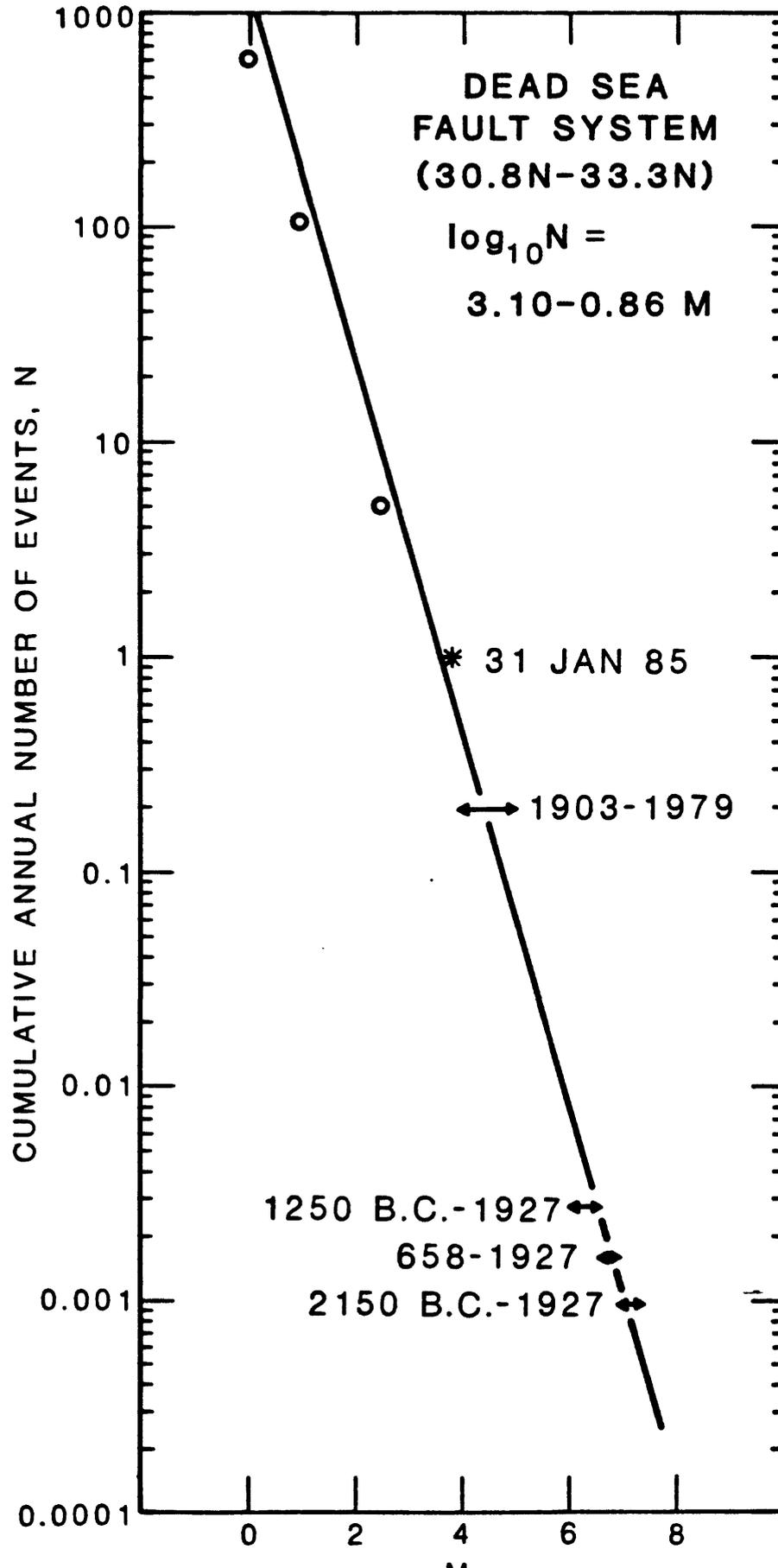
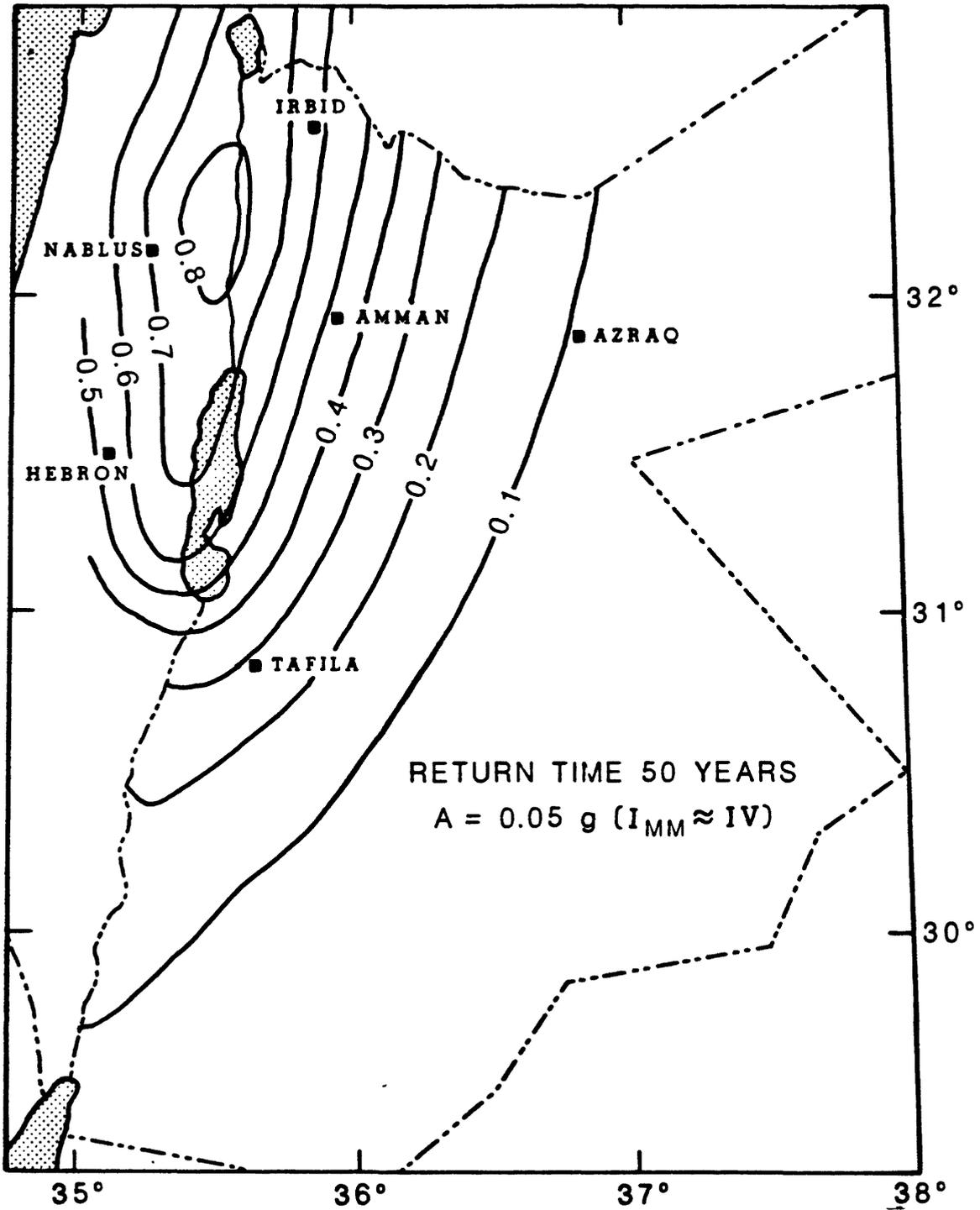


Figure 5-2: Equi-Risk (Probability) Contours for Jordan and Vicinity for Seismic Intensities of ~VI in 50 years.



One can also further allow for the decrease in the average intensity of shaking or peak horizontal ground acceleration with distance from the causative fault or epicentral region by the introduction of the proper attenuation relation for the parameter desired. Such a map shows seismic risk expressed as probability contours for a specified value of acceleration or intensity to be expected over a selected interval of time, say 50 years. Figure 5-2 shows such a map for the Dead Sea Rift and Jordan (modified from Ben-Menahem et al., 1982) expressing the equi-risk (probability) contours for a peak ground acceleration of 0.05g ( $I_{MM} \approx VI$ ) expected within a 50 year time window.

Ultimately, it is planned to install a network of strong motion accelerographs in Jordan. This network, coupled with the existing network, operating on the western side of the Dead Sea Rift zone, should permit a further refinement of the assessment of seismic risk in Jordan.

## **6. Acknowledgments**

This research was supported by the Natural Resources Authority of the Hashemite Kingdom of Jordan and the United States Agency for International Development. Valuable criticisms were made by Tom Hanks of the U.S. Geological Survey, Menlo Park, California.

## 7. References

1. Arieh, E., Peled, U., Kafri, U., and Shaal, B., The Jordan Valley Earthquake of September 2, 1973, Israel Jour. of Earth Sciences, **26**, 112-118, (1977).
2. Arvantakis, G.L., Essai sur le climat de Jerusalem, Bull. Inst. Egypte, Ser. 4, vol. 4, 178-189, (1903).
3. Ben-Menahem, A., Earthquake Catalog for the Middle East (92 B.C. - 1980 A.D.), Bull. Geof. Teor. Appl., **21**, 245-310, (1979).
4. Ben-Menahem, A., Vered, M., and Brooke, D., Earthquake Risk in the Holy Land, Bull. Geof. Teor. Appl., **24**, 175-203, (1982).
5. Ben-Menahem, A., Aboodi, Vered, M. and Kovach, R.L., Rate of Seismicity of the Dead Sea Region over the past 4000 years, Phys. Earth and Planetary Interiors, **14**, 17-27, 1977.
6. Evernden, J.F., and Thomson, J.M., Seismic Intensities: their Importance, Predictability, and Use, U.S. Geological Survey Open-File Report 86-401, 119-122, (1986).
7. Kovach, R.L., Andreasen, G., Gettings, M., and Healy, J., Seismicity of Western Jordan, U.S. Geological Survey Open File Report 86-561, 24 pp., (1986).
8. Milne, J., Catalogue of Destructive Earthquakes, Report British Association for the Advancement of Science, **80**, 694-740 (1911).
9. Perrey, A., Memoire sur les Tremblement de Terre Resentis Dans La Peninsule Turco-Hellenique et en Syrie, Memoires Couronnes et Memoires de Savants Etrangers, Academie Royale de Belgique, Bruxelles, **23**, 1-73, (1849).
10. Trifunac, M.D., and Brady, A.G., On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Ground Motion, Bull. Seismological Soc. Amer., **65**, 139-162, (1975).
11. Vered, M., and Striem, H., A Macroseismic Study and the Implications of Structural Damage of Two Recent Major Earthquakes in the Jordan Rift, Bull. Seismological Soc. Amer., **67**, 1607-1613, (1977).
12. Willis, B., Earthquakes in the Holy Land, Bull. Seismological Soc. Amer., **18**, 73-103, (1928).